Characterization of Deep Reactive Ion Etching of Dielectric Materials

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High-aspect-ratio microstructures in silicon have been available for almost a decade due to the advent of the Bosch process. Similar high-aspect-ratio microstructures in dielectric materials such as silicon dioxide have not been available until recently. This project established base recipes for the reactive ion etching of dielectrics using a new deep reactive ion etcher (DRIE). The dielectrics of interest are silicon dioxide and silicone elastomers. There exists no commercially available high-aspect-ratio etching of silicone. With this project, LLNL now has a unique capability in advanced dielectric definition and etching. This new fabrication capability enables the generation of advanced devices for a wide variety of applications. This project involved the optimization and characterization of recipes for the deep reactive ion etching of dielectrics.

Project Goals

This project established a new LLNL capability to etch high aspect ratio structures in silicon dioxide and silicone. Basic recipes were tested to etch both materials using etch rate, mask selectivity (ratio of etch rate of substrate to the etch rate of the mask), aspect ratio (ratio of width of feature being etched to the final depth of etched feature), and sidewall profile angle as the figures of merit. These basic recipes can then be tailored to etch program-specific microdevices.

Relevance to LLNL Mission

This project has relevance to a variety of LLNL interest areas. The ability to etch dielectric materials with high-aspect ratios brings a unique fabrication technique to areas in meso-, micro-, and nanotechnology. This fabrication capability enables a new generation of devices for a wide variety of applications: chemical and biological sensors; targeting, tracking, and location; biomedical devices; high-speed optical processing; and NIF target fabrication. This project has resulted in fabrication capabilities needed for the development of meso- to microscale devices with nanoscale precision.

FY2006 Accomplishments and Results

Experiments were formulated to characterize the etch performance of silicon dioxide and silicone in a Surface Technologies Systems Advanced Oxide Etch platform. The figures of merit were

Table 1. Performance of optimized recipe for silicon dioxide (quartz).

Feature size	Aspect ratio	Etch rate	Selectivity	Profile angle
50 µm	4:1	1.25 µm/min	4.5	89˚
100 µm	2:1	1.3 µm/min	4.6	89˚
200 µm	1:1	1.4 µm/min	5	89˚
400 µm	1:2	1.5 µm/min	5.2	90˚

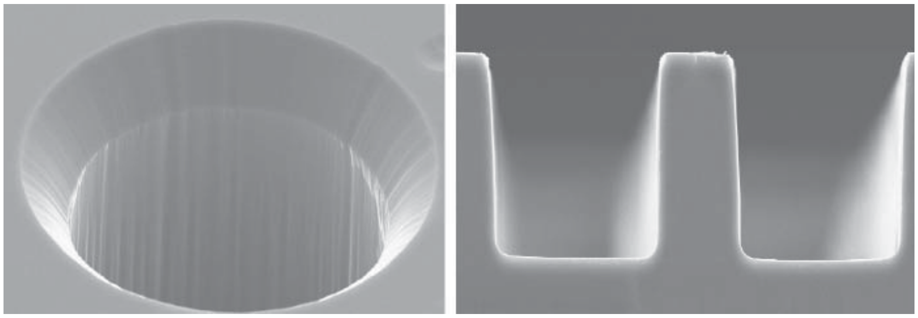

Figure 1. 100-µm holes and trenches etched 200 µm deep in a quartz (silicon dioxide) substrate using silicon shadow mask.

etch rate, sidewall profile, aspect ratio, and mask selectivity. A photolithography mask was produced which had holes and stripes which varied in feature size from 50 µm to 500 µm. Several masking materials were evaluated including silicon, chromium, and photoresist. The silicon shadow mask gave the highest selectivity to both silicon dioxide and silicone.

Several recipes were tested to optimize the figures of merit listed above using a silicon shadow mask. A summary of the results for holes etched in the silicon dioxide (quartz) substrate is given in Table 1.

Figure 1 shows the etch of 100-µm holes and trench to a depth of 200 µm in quartz (crystalline silicon dioxide). In typical high-aspect-ratio etching, trench-like features are not limited by diffusion-based processes and hence these features do not demonstrate the performance of the system. Hole-like features are diffusion-limited and provide a more difficult challenge for high-aspect-ratio etching. Hence the etch rate and the selectivity decreases as the aspect ratio increases. Overall, the figures of merit are all in desirable ranges for all the feature sizes and are similar to high-aspect-ratio silicon etch systems. Figure 2 shows an array of 200-µm holes etched 200 µm deep in quartz.

Similar experiments were conducted on silicone. Recipes were tested to optimize the figures of merit listed above using a silicon shadow mask. A summary of the results for holes etched in the silicone on a silicon substrate is given in Table 2.

Figure 3 shows the etch of 100-µm holes to a depth of 200 µm in silicone on a silicon substrate. Again, as with the quartz etch recipes, the etch rate and the selectivity decreases as the aspect ratio increases. Overall, the figures of merit are all in desirable ranges for all the feature sizes and are similar to high-aspect-ratio silicon etch systems. A wafer-to-wafer uniformity study was conducted on 15 silicone wafers to determine the repeatability of the process. The etch rate was used as the figure of merit. The results are summarized in Table 3.

In summary, base recipes for high-aspect-ratio etching of silicon dioxide and silicone were tested using a silicon shadow mask. The figures of merit are similar to the values obtained on high-aspect-ratio silicon etch systems.

Related References

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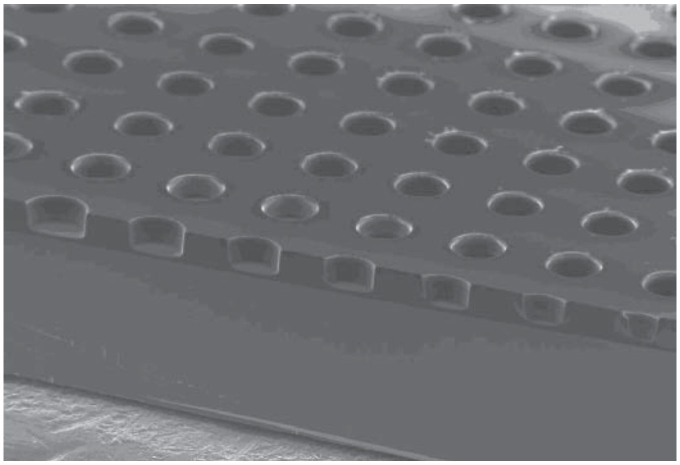

Figure 2. Array of 200-µm holes etched 200 µm deep in a quartz (silicon dioxide) substrate using silicon shadow mask.

Table 2. Performance of optimized recipe for silicone-on-silicon substrate.

Feature size	Aspect ratio	Etch rate	Selectivity	Profile angle
50 µm	4:1	1.0 µm/min	2.5	89˚
100 µm	2:1	1.15 µm/min	2.6	89˚
200 µm	1:1	1.2 µm/min	2.9	89˚
400 µm	1:2	1.25 µm/min	3.0	89˚

Table 3. Results of wafer-to-wafer uniformity study conducted on 15 silicone wafers.

Figure of merit	50 µm	100 µm	200 µm	400 µm
Mean etch rate	1.05 µm/min	1.12 µm/min	1.20 µm/min	1.32 µm/min
Run to run uniformity	5.2%	3.8%	2.9%	2.2%

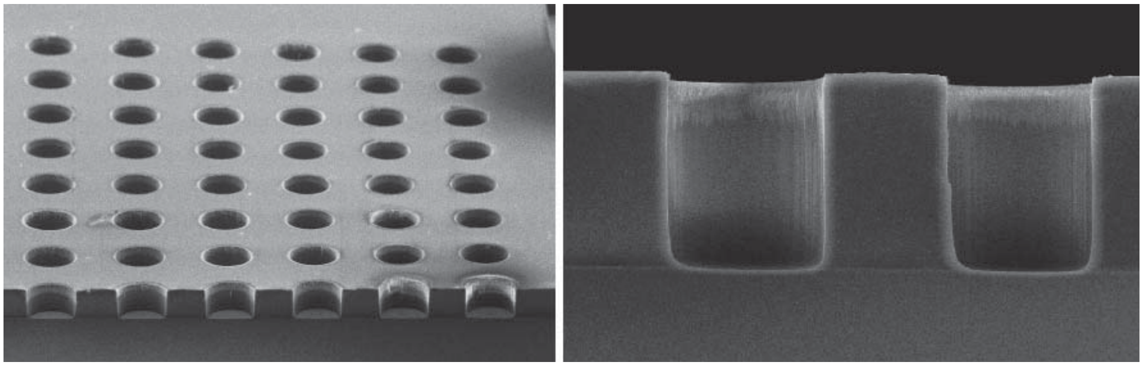

Figure 3. 100-µm holes etched 200 µm deep in silicone on a silicon substrate using silicon shadow mask.